



Percutaneous Radiofrequency Catheter Ablation for Supraventricular Arrhythmias in Children

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Nineteen procedures were performed in 17 children, aged 10 months to 17 years, using catheter radiofrequency applications for the management of malignant or drug-resistant supraventricular tachyarrhythmias. Diagnoses were junctional ectopic tachycardia in 1 patient, atrioventricular (AV) node reentrant tachycardia in 4 and accessory pathway-mediated tachycardia in 12. Accessory pathway locations were left lateral ($n = 4$), posteroseptal ($n = 3$), left posterior ($n = 2$), right posterolateral ($n = 1$), right posterior paraseptal ($n = 1$), right intermediate septal ($n = 1$) and right anterior ($n = 1$).

Ablation of accessory pathways was performed using 20 to 40 W of energy. The catheter was passed retrograde to the left ventricle in patients with a left-sided pathway and anterograde to the right atrium in those with a right-sided or posteroseptal pathway. In the 12 patients with an accessory pathway, radiofrequency applications were successful in 11 pathways and failed in 2. There were no recurrences of accessory pathway-mediated tachycardia.

Catheter ablation with high voltage direct current shock has been used for the ablation of accessory pathways or the modification or elimination of atrioventricular (AV) conduction (1). Direct current shock ablation results in explosive gas formation and generation of a shock wave (2,3). The small chamber sizes and thin walls of the immature heart may be particularly susceptible to adverse barotraumatic effects of ablative shocks (4) and there have been few reports (5-7) of the use of such techniques in children. More recently, transcatheter application of radiofrequency energy has been used in adults to eliminate AV conduction in patients with atrial arrhythmias (8), to modify AV node function in patients with AV node reentrant tachycardia (9) and to ablate accessory pathways (10-13). Radiofrequency current produces tissue injury solely through resistive heating and is not associated with explosive gas formation (14).

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Atrioventricular node reentrant tachycardia was treated by AV node modification using 15 W of energy applied until first degree AV block occurred. After radiofrequency catheter ablation, there was a prolonged AH interval, tachycardia was not inducible and tachycardia recurred in one patient. For the patient with junctional ectopic tachycardia, 15 to 18 W of energy was delivered at the site of the maximal His bundle electrogram until sinus rhythm and normal AV conduction appeared. After a recurrence, a second procedure abolished tachycardia and AV conduction.

In summary, radiofrequency catheter ablation was initially successful in 17 of 19 procedures and ultimately curative in 14 (82%) of 17 patients with no serious complications. Radiofrequency catheter ablation appears to be a safe and effective method for the management of supraventricular tachyarrhythmias in children.

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The absence of barotrauma makes the radiofrequency technique particularly appealing for use in children. This report describes our initial experience with the use of radiofrequency catheter ablation in the management of children with sustained symptomatic supraventricular tachyarrhythmias.

Methods

Patient selection. All patients were referred to our institution for evaluation and management of frequent or incessant supraventricular tachycardia. After an initial evaluation that included history, physical examination, electrocardiogram (ECG) and in some cases ambulatory 24 h ECG monitoring and echocardiography, each patient underwent a standard electrophysiologic study with intravenous sedation or general endotracheal anesthesia. The mechanism of tachycardia was confirmed in all cases.

Patients who would have otherwise been considered for surgical management became candidates for radiofrequency catheter ablation or modification. In practice, this meant that at least one of the following criteria was satisfied: 1) an accessory pathway was present in a patient with syncope or aborted sudden death; 2) supraventricular tachycardia occurred frequently despite treatment with several antiarrhyth-

mic agents; or 3) antiarrhythmic agents partially or completely controlled supraventricular tachycardia but were associated with unacceptable side effects. Seventeen patients met these criteria and underwent the catheter ablation procedure.

After being informed of the investigational nature of the procedure and the possible risks involved, patients and their parents or guardians gave written informed consent for the catheter ablation procedure. The protocol was approved by the Committee on Human Research at our institution.

The Radiofrequency Catheter Ablation Procedure

For the first case, radiofrequency energy was supplied by an electrosurgical unit (Microvasive, Bicap 4005) that supplied continuous unmodulated current at 550 kHz. Subsequently, a radiofrequency lesion generator system was used (Radionics RFG3B) to supply continuous unmodulated current at 330 kHz. Energy was applied between the distal pole of a custom 6F bipolar or steerable quadripolar electrode catheter with a large (4 mm) distal electrode ("ablation catheter") (Mansfield Scientific) and a large surface area skin electrode placed over the left scapula (R2 Corporation), regardless of the site of the ablation.

Patients with a left-sided accessory pathway or intracardiac shunting received anticoagulant therapy using approximately 150 U/kg of intravenous heparin. Activated clotting times were monitored during the study and additional doses of heparin were given as necessary.

Accessory pathway ablation. Accessory pathway location was classified according to the pattern of earliest retrograde atrial activation. In patients with a left-sided accessory pathway, the ablation catheter was introduced from the femoral artery retrograde to the left ventricle and positioned against the AV ring, using the coronary sinus catheter electrode as a guide (Fig. 1). In patients with a posteroseptal accessory pathway, the ablation catheter was advanced from the femoral vein to the right atrium and the tip was positioned on the AV ring just inferior to the os of the coronary sinus. In patients with a right-sided pathway, a transluminal ventricular pacing wire (V-pace, Spectramed, Inc.) was used to map the tricuspid annulus by way of the right coronary artery (15) as follows. After anticoagulation and right coronary angiography, the transluminal ventricular pacing wire was advanced through a Judkins 7F right coronary catheter and into the right coronary artery to the crux of the heart. A unipolar electrogram was recorded from the distal electrode during orthodromic tachycardia, and the distal pole was positioned at the site of the earliest retrograde atrial activation. The ablation catheter was advanced from the femoral or internal jugular vein and positioned against the right AV ring, using the coronary artery wire as a guide. Coronary angiography was repeated after removal of the wire.

In all cases, the ablation catheter was positioned to record both atrial and ventricular electrograms and the

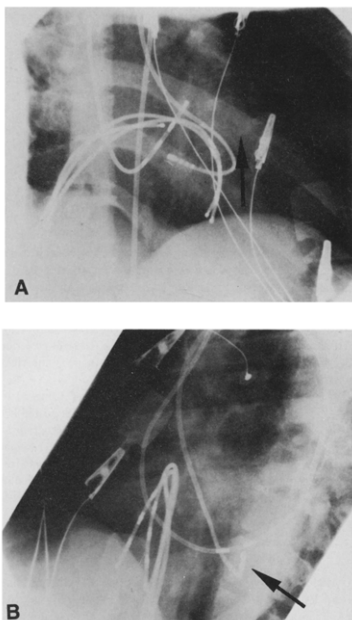


Figure 1. Patient 6. Radiographs of catheter positions during ablation of left posterior accessory pathway. A, 30° right anterior oblique projection; B, 60° left anterior oblique position. Note the ablation catheter with tightly spaced electrodes and a large distal electrode introduced from the aorta into the left ventricle and pointing at pole 3 of the coronary sinus catheter (arrows).

shortest ventriculoatrial (VA) interval during orthodromic supraventricular tachycardia. Radiofrequency energy was applied at a power output of 15 to 35 W for 100 s. Radiofrequency application was immediately stopped if a sudden increase in voltage or sudden decrease in current, implying an increase in impedance, was observed. Programmed stimulation was repeated ≥ 30 min after the last application of radiofrequency energy to assess the effects of the procedure on anterograde conduction, retrograde conduction and the inducibility of arrhythmias.

AV node modification for AV node reentrant tachycardia. The ablation catheter was positioned at the low septal right atrium and a bipolar electrogram was recorded from the

Table 1. Radiofrequency Ablation of Accessory Pathways in 12 Patients

Pt No.	Age (yr)/Gender	Weight (kg)	Pathway		Applications (no.)	Result	Follow-Up EPS Interval (days)	Clinical Follow-Up (mo)	SVT at Follow-Up	Medication at Follow-Up
			Location	Pre-excitation						
1	14/F	56.4	Left lateral	0	3	S	91	7	0	0
2	8/F	36.5	Right anterior	+	6	U	—	6.75	+	Flecainide
3	15/M	71	Left lateral	+	2	S	3	6	0	0
4	13/M	41	Right posterolateral	+	4	S*	85	5.75	0	0
4	13/M	41	Right posterior paraseptal	+	23	S	3	—	0	0
5	15/M	77	Posteroseptal	+	3	S	42	4.75	0	0
6	16/F	50.4	Left posterior	+	2	S	—	4.25	0	0
7	13/M	51	Posteroseptal	+	5	S	71	3.75	0	0
8	17/F	85.5	Left lateral	0	5	S	—	3	0	0
9	3/M	13.3	Posteroseptal	0†	10	S	—	2.5	0	0
10	12/F	36.4	Left lateral	+	5	S	—	2.25	0	0
11	16/M	70	Left posterior	+	22	U	—	1.75	+	Pigoxin
12	7/F	25.4	Right intermediate septal	0†	19	S	—	1.25	0	0

*Procedure initially successful, with subsequent appearance of second accessory pathway; second ablation successful. †These two patients had the permanent form of junctional reciprocating tachycardia. C = concealed; EPS = electrophysiologic study; F = female; M = male; Pt = patient; S = success; SVT = supraventricular tachycardia; U = unsuccessful; 0 = no; + = yes.

distal pair of electrodes. The catheter was positioned to record the largest His bundle electrogram. The catheter was then withdrawn about 5 mm to a position that recorded a large atrial electrogram and no His bundle electrogram. Pacing catheters were positioned in the high right atrium and right ventricular apex. During atrial overdrive pacing, radiofrequency energy was then applied from the distal pole of the ablation catheter at a power output of 10 to 20 W. The application was stopped when a 50% prolongation of the PR interval was observed or if there was an increase in impedance. Programmed stimulation was performed ≥ 30 min after the last application of radiofrequency energy, both with and without the infusion of isoproterenol, to assess the effects of the procedure on anterograde conduction, retrograde conduction and the inducibility of arrhythmias.

Ablation of junctional ectopic tachycardia. As previously reported (16), a catheter was positioned in the right ventricle for temporary pacing, and the ablation catheter was positioned to obtain the maximal atrial electrogram amplitude with a prominent His bundle electrogram. Radiofrequency energy was delivered at a power output of 15 to 18 W.

Follow-up studies. All patients were observed in the hospital for ≥ 2 days. A 12 lead ECG and a 24 h ambulatory ECG were obtained for each patient. All patients who had AV node modification underwent an esophageal electrophysiologic study >48 h after the initial procedure to assess AV conduction and were followed up regularly as outpatients.

Results

There were 19 procedures performed in 17 patients aged 10 months to 17 years (Tables 1 and 2). Twelve patients had an accessory pathway, four had AV node reentrant tachycardia and one had congenital junctional ectopic tachycardia. Radiofrequency catheter ablation was initially successful in 17 (89%) of the 19 procedures and ultimately curative in 14 (82%) of the 17 patients.

Accessory pathway ablation (Patients 1 to 12, Table 1). Successful procedures required a median of 5 applications of radiofrequency energy (range 2 to 23) at an applied power output of 16 to 35 W. The mean duration of successful

Table 2. Radiofrequency Modification and Ablation at the Atrioventricular Junction in Five Patients

Pt No.	Age (yr)/Gender	Weight (kg)	Diagnosis	Applications (no.)	Result	Follow-Up EPS Interval (days)	Clinical Follow-Up (mo)	SVT at Follow-Up	Medication at Follow-Up
13	15/F	57.3	AVNRT	1	S	3	8	0	0
14	15/M	64.7	AVNRT	3	S	7	7.75	0	0
15	13/F	45.1	AVNRT	3	S	2	6.25	0	0
16	16/F	58.8	AVNRT	3	S	2	3.25	+	0
17	10.5 mo/M	8.2	JET	14	S*	—	16	0	0

*Second procedure. First procedure was transiently successful, but junctional ectopic tachycardia (JET) recurred 2 weeks later; no recurrence since second ablation. AVNRT = atrioventricular node reentrant tachycardia; other abbreviations as in Table 1.

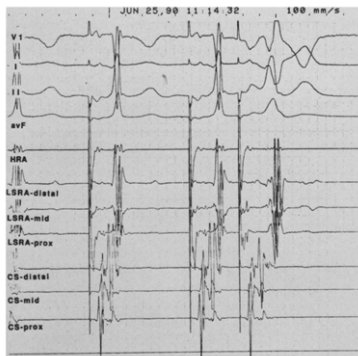


Figure 2. Patient 3. Recordings at baseline electrophysiologic study before ablation of a left lateral accessory pathway. Atrial extrastimulation from the high right atrium (HRA), using a drive cycle length of 600 ms, with an induced atrial premature complex introduced 290 ms after the last driven complex (A_1 - A_2). Note pre-excitation seen on surface leads during the drive, which becomes more prominent on the premature beat, and the short AV interval in the coronary sinus electrograms. Time marks are at 50 ms intervals. CS-distal, mid, prox = coronary sinus at distal, middle and proximal positions, respectively; LSRA-distal, mid, prox = low septal right atrium at distal, middle and proximal positions, respectively; V1, I, II, avF = surface electrocardiographic leads.

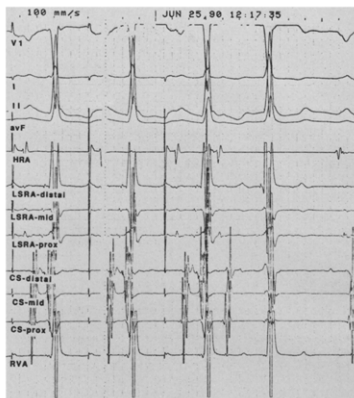


Figure 3. Patient 3. Recordings from the electrophysiologic study after ablation of the accessory pathway. Atrial extrastimulation from high right atrium (HRA), using a drive cycle length of 450 ms and an A_1 - A_2 interval of 240 ms. Note absence of pre-excitation on surface leads during the drive, as well as on the premature atrial beat, and normalization of the atrioventricular interval in the coronary sinus electrograms. Time marks are at 50 ms intervals. RVA = right ventricular apex; other abbreviations as in Figure 2.

procedures after insertion of electrode catheters was 167 min (range 71 to 254).

Eleven of the 13 procedures were completely successful. In the seven successful procedures in patients with pre-excitation, the delta wave disappeared (Fig. 2 and 3). Immediate restudy showed the absence of pre-excitation with atrial extrastimulation in these 7 procedures, decremental VA conduction in 8 of the 11 successful procedures and absent VA conduction in 3 of 11 procedures. Supraventricular tachycardia was no longer inducible. Atrial fibrillation was induced in one patient before ablation and was still inducible after the procedure. Atrial tachycardia was not inducible in any patient before the procedure, and two to three beats of atrial tachycardia were inducible in two patients after ablation. None of these patients had atrial arrhythmias on follow-up 24 h ECG monitoring.

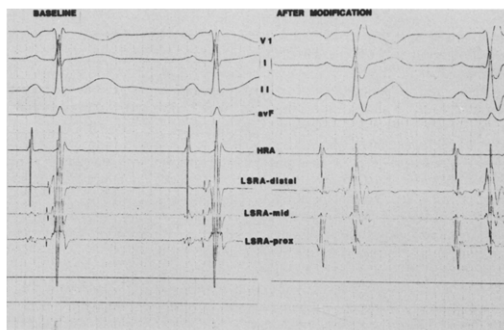
Case descriptions (Table 1). In Patient 2, a patient with a right anterior accessory pathway, multiple applications of radiofrequency energy to the atrial side of the AV valve ring using an ablation catheter introduced from the femoral vein failed to alter anterograde or retrograde conduction and supraventricular tachycardia was still inducible. The path-

way was not approached from the internal jugular vein. In Patient 11, a patient with a left posterior accessory pathway, application of radiofrequency energy at 16 to 20 W caused loss of pre-excitation on four separate occasions, with return of pre-excitation after 5 min in each case. Applications on either side of the ablation site had no effect, and higher power outputs led to an immediate increase in impedance.

In Patient 4, who had Ebstein's anomaly of the tricuspid valve, an atrial septal defect and a right posterolateral accessory pathway, the procedure was successful in abolishing pre-excitation. However, supraventricular tachycardia was subsequently induced. A second procedure was performed and a second accessory pathway (right posterior paraseptal) was identified and successfully ablated. Three days later, the patient underwent surgical closure of his atrial septal defect. At operation, inspection of the ablation area by the surgeon revealed no evidence of cardiac trauma. VA conduction was absent, there was no pre-excitation and the defect was closed with a cardiopulmonary bypass time of 19 min. There were no arrhythmias in the immediate post-operative period.

Two of these 12 patients had the permanent form of junctional reciprocating tachycardia. In the first (Patient 9), discontinuation of treatment with flecainide, propranolol and

Figure 4. Patient 14. Recordings at electrophysiologic study before and after atrioventricular node modification. Note the moderate prolongation of the PR and AH intervals in sinus rhythm and the minimal right ventricular conduction delay evident in the surface leads. Time marks are at 50 ms intervals. Abbreviations as in Figure 2.



digoxin 1 week before the procedure led to daily prolonged attacks of typical supraventricular tachycardia. Tachycardia was easily induced at the time of the procedure. After 10 applications of radiofrequency energy to the posteroseptal region, tachycardia was still inducible but was difficult to induce and was nonsustained. This patient has remained free of tachycardia without medication for the 2.5 months since the procedure.

The second patient (Patient 12) developed incessant tachycardia after use of digoxin and flecainide was discontinued 1 week before the procedure. Several applications of radiofrequency energy to the posteroseptal region terminated tachycardia, but the arrhythmia was still inducible. The catheter was moved to a position just medial to the coronary sinus os on the right AV ring in the intermediate septal region, where a slightly shorter local VA time and a possible tiny accessory pathway potential were recorded. A single application at this site eliminated tachycardia as well as VA conduction and tachycardia was no longer inducible despite infusion of isoproterenol. This patient has done well without medication during the short follow-up interval of 5 weeks.

Follow-up electrophysiologic study, performed in 6 of the 10 patients who had a completely successful procedure,

confirmed the absence of accessory pathway function (Table 1). All 10 were completely asymptomatic without medication after a follow-up interval of 1.25 to 7 months. Six of the 10 successfully treated patients who had pre-excitation before the procedure had no pre-excitation on follow-up ECG. Follow-up 24 h ECG monitoring was performed in all 12 patients who underwent attempted accessory pathway ablation. Patient 4, who had Ebstein's anomaly and had undergone ablation followed by surgical closure of an atrial septal defect, was found to have asymptomatic nonsustained atrial tachycardia and premature atrial complexes. No other patient had ventricular or atrial ectopic activity.

AV node modification for AV node reentrant tachycardia (Patients 13 to 17, Table 2). Four patients underwent successful AV node modification for this arrhythmia (Fig. 4). Before modification, three of four patients had anterograde dual AV node conduction curves demonstrable either at baseline study ($n = 2$) or with the administration of isoproterenol ($n = 2$). None of the four patients had retrograde dual AV conduction curves demonstrable. Immediate testing after radiofrequency AV node modification showed decremental VA conduction in three of the four patients and absent VA conduction in one (Table 3). Dual AV node conduction curves were not demonstrable in any patient

Table 3. Atrioventricular Node (AVN) Recentry: Electrophysiologic Data in Four Patients

Pt No.	Pre-modification Findings (ms)				Postmodification Findings:			Findings With Isoproterenol (ms)		
	PR	AVBCL	VAHCL	Dual AVN Pathways	PR	AVBCL	VABCL	PR	AVBCL	VABCL
13	110	300	280	No	170	300	400	130	240	300
14	120	350	370	Yes	170	340	400	130	250	350
15	125	340	430	Yes	170	280	>550	130	250	480
16	160	340	300	Yes	230	330	700	170	230	270

AVBCL = atrioventricular block cycle length; PR = PR interval; Pt = patient; VABCL = ventriculoatrial block cycle length.

after AV node modification, suggesting that selective ablation of fast pathway fibers had been accomplished. The PR and AH intervals were prolonged in all four patients and AV node reentrant tachycardia was not inducible. AV node effective refractory periods and Wenckebach cycle lengths were prolonged but still within normal limits. With isoproterenol infusion sufficient to increase the sinus rate by 20%, AV node effective refractory periods and Wenckebach cycle lengths were normal and VA conduction was present and slightly decreased in all four patients. Again, AV node reentrant tachycardia was not inducible. In all four patients, four to five beats of intraatrial reentrant tachycardia occurred with very early atrial extrastimuli.

Follow-up esophageal electrophysiologic studies in all four patients within the 1st week showed no inducible tachycardia and normal AV block cycle lengths and effective refractory periods (Table 2). All four had been frequently symptomatic before the procedure and three of the four were asymptomatic after a follow-up interval of 3 to 8 months. The fourth patient (Patient 16), who had previously had weekly episodes of tachycardia, has had one episode of tachycardia in the 3 months since the procedure, but is receiving no medication.

Ablation of junctional ectopic tachycardia (Table 2). Patient 17 underwent two procedures for ablation of congenital junctional ectopic tachycardia and has been previously described (16). The patient presented at 1 day of age with incessant tachycardia at rates of 180 to 270 beats/min and was eventually managed with amiodarone, digoxin and propranolol with moderate rate control. A pacemaker was implanted at age 5 months to protect against the sudden development of AV block (17). Because of severe developmental delay, radiofrequency ablation was performed at age 10 months. After the first procedure with three applications of radiofrequency current, he had normal sinus rhythm. Administration of all medications was stopped, but 2 weeks later incessant tachycardia recurred at a rate of 260 beats/min. A second procedure with 14 applications of radiofrequency current resulted in complete AV block with ventricular rates of 80 to 110 beats/min. Fifteen months later, this patient remains free of tachycardia, takes no medication and is not pacemaker dependent.

Complications. During the application of radiofrequency energy, no patient experienced significant pain or manifested hypotension or arrhythmias. No major complications were seen after any procedure. Right coronary angiography was performed at the end of the three procedures in which an intraluminal right coronary artery wire was used for mapping. These angiograms showed no evidence of coronary obstruction. In Patient 1, a large hematoma occurred at the inguinal entry site but treatment was not required. Patient 11 had moderate pain in the right foot after a prolonged attempt at ablation using the right femoral artery; microembolism was considered a possible cause. Detailed blood flow studies of the foot showed no major abnormalities and the patient recovered promptly without treatment.

Creatine kinase levels were measured in 12 patients. Four hours after the procedure, the mean level was 370 U/liter (range 110 to 969) with a mean MB fraction of 13.8 U/liter (range 0 to 39). The next morning, the mean level was 252 U/liter (range 100 to 671) with a mean MB fraction of 5.8 U/liter (range 0 to 22). Follow-up ECGs showed no changes suggestive of myocardial ischemia or infarction. Follow-up echocardiograms 2 to 3 h after the procedure were obtained in 11 patients and showed no pericardial effusion, intracardiac thrombi or new AV or semilunar valve insufficiency.

Discussion

Ablation using direct current shock. Since the initial description (18,19) of catheter ablation of the AV junction in adults using direct current shock, the technique has been extended for use in patients with all types of supraventricular tachycardia. There is now a large experience with direct current catheter ablation of posteroseptal accessory pathways (20-22) and more recently of pathways in other locations (3,10,23). Direct current shock has been used to modify the AV node in patients with AV node reentrant tachycardia (24), to produce complete AV block in patients with refractory supraventricular arrhythmias (25) and to ablate ectopic atrial tachycardia and ventricular tachycardia foci (7,26,27).

Experience with direct current shock ablation in children, however, is limited. Direct current shocks of 50 to 200 J were used by Gillette et al. (7) for ablation of ectopic atrial tachycardia foci in four children, with success in two. Gillette et al. (6) also used direct current shocks of 1.5 to 3 J/kg successfully in two children with congenital junctional ectopic tachycardia. Smith et al. (28) used shocks of 25 to 300 J delivered to the mouth of the coronary sinus in four children, aged 2 to 10 years, with the permanent form of junctional reciprocating tachycardia, achieving permanent ablation of the retrograde accessory pathway in only one and causing permanent interruption of anterograde conduction in another patient requiring pacemaker implantation. The other two patients had transient loss of retrograde accessory pathway function and had fewer episodes of supraventricular tachycardia after the procedure.

Bromberg et al. (5) reported on six children, aged 8 to 15 years, with an accessory pathway who underwent a direct current catheter ablation procedure. Only two patients were without signs of accessory pathway function at follow-up study and three patients underwent surgical ablation of the accessory pathway. Of the three patients not sent to surgery, two were considered cured and were without clinical supraventricular tachycardia at follow-up evaluation and one had a return of pre-excitation and supraventricular tachycardia thought to be due to AV node reentrant tachycardia. AV node modification by direct current transcatheter shock or radiofrequency energy for AV node reentrant tachycardia has not been reported in children.

Safety issues. Although direct current shock ablation has been shown to be very effective, the mechanism of action involves the production of a shock wave with explosive gas formation, which in turn damages tissue (2). Thus, complications are related to barotrauma and have included pericardial effusion, ventricular fibrillation and cardiac perforation with tamponade in adults (3,22,23,25), as well as inadvertent AV block in one child (28). Moak et al. (4) described cardiac perforation in puppies that received direct current catheter shocks of 200 J to the atrium and two died with refractory ventricular fibrillation or low cardiac output after shocks of 400 J. Although experience with direct current shock ablation in children is limited, the risk of barotraumatic complications is potentially of greater importance in children given the smaller size of the heart. The availability of radiofrequency energy for use in ablation procedures has provided the potential for a safer technique of catheter ablation. Radiofrequency lesions are formed through resistive heating and the lesions are quite small, on the order of 0.2 cm³ (14). Shock waves and explosive gas formation do not occur and general anesthesia is not necessary. In studies (29) of adults using catheter radiofrequency energy for ablation of cardiac arrhythmias, no serious complications have been reported during the procedures.

When considering the possibility of long-term complications of the procedure in children, the question of subsequent atrial or ventricular arrhythmias as well as the possibility of coronary artery occlusion must be considered. Radiofrequency energy has now been applied successfully and safely in adults for AV node ablation (8,10,30). AV node modification in AV node reentrant tachycardia (9) and ablation of left-sided accessory pathways (11,12) and right anteroseptal pathways (13) and serious atrial or ventricular arrhythmias have not been noted. Saul et al. (31) reported preliminary data on successful accessory pathway ablation in three patients, aged 5, 13 and 15 years, respectively, with four procedures using radiofrequency energy; there were no reported complications. Although several of our patients had several beats of atrial tachycardia inducible immediately after the procedure, none of them were found to have atrial or ventricular arrhythmias subsequently. Our Patient 4, who subsequently developed nonsustained atrial tachycardia, did not have inducible arrhythmias after the second ablation procedure. His atrial ectopic activity may be partially explained by subsequent surgical repair of atrial septal defect and chronic tricuspid regurgitation. Acute coronary spasm has not been seen with radiofrequency energy application, and long-term problems with coronary artery occlusion or damage have not been observed (32). One pathologic study (33) of canine hearts subjected to application of radiofrequency energy to both the AV node and the right and left AV grooves found no evidence of damage to the coronary arteries. However, the potential for such problems may be present. The potential risk must be carefully weighed against the risks of surgery as well as the risk of continued medical management, and children who undergo radiofrequency

ablation must be followed up far into the future to monitor for the possible development of new arrhythmias or coronary artery occlusion.

Technical aspects. We used the retrograde approach for ablation of left-sided accessory pathways, as have other investigators (12). However, the mitral valve ring may also be approached by using standard pediatric catheterization techniques for crossing the interatrial septum either by way of a patent foramen ovale (5) or atrial septal defect or by transseptal puncture (23,31).

Accessory pathways in children may occur in association with congenital heart disease, especially Ebstein's anomaly of the tricuspid valve (34), as in our Patient 4. The presence of supraventricular tachycardia is often identified in such patients at the time of diagnostic cardiac catheterization when catheter manipulation induces tachycardia. When such patients undergo surgical repair of their cardiac defect, the accessory pathway should generally be ablated before or at the time of operation to minimize the risk of postoperative arrhythmias (35). Intraoperative ablation by the endocardial route prolongs the operation and must be done during cardiopulmonary bypass. The availability of the radiofrequency technique may allow ablation of the accessory pathway before surgery in patients such as ours, thus shortening the time of cardiopulmonary bypass and decreasing the risks of the operation.

Conclusions. We found radiofrequency energy to be safe and effective in the nonpharmacologic management of children with supraventricular tachyarrhythmias. The excellent results and apparent safety of the technique suggest that it may obviate the need for surgical management or lifelong drug therapy in many patients. Radiofrequency catheter ablation techniques should be seriously considered in children with life-threatening or drug-refractory arrhythmias and those with unacceptable side effects from medication.

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